MS-47664 revised

Screening Maritime Shipping Containers for Weapons of Mass Destruction[1]

Christina Rudzinski[1], David Masters[2], Allan Buck[1], Martha Wall[1], David Tremblay[1], Edward Wack[1]

[1] MIT Lincoln Laboratory
Lexington, MA
CRudzinski@LL.MIT.EDU

[2]Department of Homeland Security, Science and Technology Directorate
Washington, DC
David.Masters@DHS.GOV

Abstract— *Tens of millions of shipping containers enter U.S. seaports every year carrying commerce surpassing 1.5 trillion dollars in value. As a result, the maritime shipping industry offers an attractive channel for terrorist organizations to smuggle weapons of mass destruction into the U.S., or to cripple the U.S. economy by directly attacking major ports and maritime infrastructure. In order to prevent such an event from occurring, the Department of Homeland Security has initiated the SAFECON and TRUST programs aimed at improving security measures to detect anomalous goods such as these threats in container air. These programs are working to develop aggressive solutions that minimize any disruption to the flow of commerce by identifying or developing air-sample based sensors that can be installed on port gantry cranes or housed within shipping containers themselves. This paper describes many of the challenges associated with the detection of threats inside shipping containers using both approaches as well as the DHS Container Security Test Bed that is being established at the Transportation Security Laboratory to enable realistic evaluation of technologies. Data highlighting many of the challenges including the concentrations and movement of threat simulants inside containers, background signatures, and air sampling capabilities will be presented. This information and the additional data that is being collected at the test bed will allow us to derive sensor and operational requirements and enable the intelligent design and selection of critical technologies.*

Keywords; Container security, chemical biological defense, sensors, testbed

I. Introduction

DHS Customs and Border Protection (CBP) and the Transportation Security Administration (TSA) will be required to scan 100% of high risk shipping and cargo containers for dangerous chemical, biological, radiological, nuclear, and explosives (CBRNE) materials to prevent their unlawful transportation into the United States. CBP and TSA share a mission to secure our borders and transportation systems not only from a devastating attack, but also to seize smuggled narcotics, weapons, agricultural products, other contraband, and human trafficking. In order to meet these challenges, new screening technologies are needed to rapidly identify a wide range of threats and suspicious substances without changing the existing cargo supply chain, the current operating architectures, and interrupting the flow of commerce.

The SAFECON-TRUST project was undertaken as a DHS S&T HSARPA program to develop innovative technologies and a prototype device with high payoff to protect the nation from WMD and other threats smuggled in intermodal shipping containers at or before entering the nation's ports and borders. The program will focus on two primary screening methods, one external to the container while it is being moved from conveyance to ship or vice versa, and an alternative in-situ method to sample, detect, and report dangerous cargo from inside a sealed container while in transit.

Many of the technologies identified in the SAFECON-TRUST approach are beyond the basic research stage, yet are not well tested or established in their own right and will be adapted or applied to realize a capable prototype. To effectively and economically detect CBRNE/P threats and contraband in intermodal containers poses a unique and specific set of technology challenges that are being addressed in the SAFECON-TRUST program.

The SAFE Container (SAFECON) project takes a portal development approach by sampling the air in shipping containers while the container is being loaded onto or off-loaded from a ship, operating entirely external to the shipping container and require no modification to the current inventory of containers.

The Time Recorded Ubiquitous Sensor Technologies (TRUST) approach is based on exploiting long dwell phenomenology, sampling threat vapors and particulates from within the container while in transit once it is loaded and

1. This work is sponsored by the DHS S&T under Air Force Contract #FA8721-05-C-0002. Opinions, interpretations, recommendations and conclusions are those of the authors and are not necessarily endorsed by the United States Government.

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **2010**	2. REPORT TYPE	3. DATES COVERED **00-00-2010 to 00-00-2010**

4. TITLE AND SUBTITLE **Screening Maritime Shipping Containers for Weapons of Mass Destruction**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **MIT Lincoln Laboratory,244 Wood St,Lexington,MA,02420-9108**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT
Tells of millions of shipping containers enter u.s. seaports evel), year carrying commerce slIIpassiJ1g 1.5 trillion dollars in value. As a result, the maritime shipping inc/uslly offers an attractive channel for terrorist organizations 10 smuggle weapons of mass destruction il110 the u.s., OJ' to cripple the u.s. economy by directly attacking major ports Gild maritime infrastructure. In order to prevent slIch (Ill event from occurring, the Department of Homelalld Seclirity has inilialed Ihe SAFECON and TRUST programs aimed al improving security measlires to detect anomalolls goods such as these threats ill container air. These programs are working to develop aggressive solutions that minimize any disruption to the flow of commerce by identifying or developing airsample based sensors that can be installed on port gal1tlY cranes or housed within s/lIiJping containers themsel

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**7**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

sealed.

Both SAFECON and TRUST approaches are required to sample, detect, and identify threat substances and contraband contained within a maritime shipping container; such as chemical and biological agents, explosives, and human cargo, contraband and anomalous substances that may be associated with various threats. Both approaches are exploring large volume vapor and particulate sample collection and preparation techniques, and various sensor modalities within their respective size, weight, and power constraints.

Shipping containers are natural repositories of leaked or trace contamination of threats and contraband placed and stored inside. Containers also prevent contamination from background sources or in many cases from adjacent containers. Sampling the headspace provides an opportunity to capture vapors and/or particulate threats and measure them directly rather than indirectly by inference or other difficult to characterization techniques. This makes them ideal test subjects for comprehensive primary inspection, however, a complete, or "representative," sample of the container's atmosphere is required to adequately confirm that a container is safe or suspicious. High vapor pressure threats are relatively homogeneous; however, many threat substances make this a difficult proposition, namely, low vapor pressure threats and particles < 1micron in size.

The program is investigating several methods to develop and demonstrate a smart collector, one that can reject innocuous sample backgrounds, yet collect and pass atmospheres of high interest. Our intent is to develop a highly capable sample collection and preparation subsystem and utilize existing detection equipment whenever possible. This strategy will make the most out of available and sometimes complex detection methods by preparing samples with minimal clutter and possibility of saturation.

II. NEED FOR TESTBED

The Container Security Test Bed (CSTB) is a new addition to the Transportation Security Laboratory (TSL) established to test and demonstrate a wide range of container security technologies. CSTB will allow system developers to step out of the laboratory into a more realistic environment and test with relevant and simulated backgrounds and threats. CSTB closely replicates the conditions found in our nation's seaports, including the ability to lift and move a variety of shipping containers, simulating in-transit, dynamic conditions and the loading and unloading of container ships.

The CSTB is intended to provide a relevant environment for government, industry, and academia to experiment, test, and demonstrate container scanning methods, port security, and automation technology and systems. The test bed has been built to support the maximum range of activities, from concept exploration to system test and evaluation (T&E) and beyond. The test bed is not limited to supporting container scanning technologies only. Due to a large footprint under and surrounding the crane, other container handling technologies can be tested and demonstrated.

III. CONTAINER SCREENING TEST BED

A. *Crane and Spreader Bar Assemblies*

The CSTB relies on a bridge crane to move an instrumented cargo container during baseline testing and experimentation much in the same way a cantilever crane moves containers to and from ship to shore and vice versa (See Figure 1). The CSTB crane operates at the velocities and accelerations typically encountered at real ports around the world. A standard port spreader bar is attached to the CSTB crane to provide the safest and most realistic environment and operational conditions possible. Any threat detection system that needs to exploit the dynamics of real port operations can be subjected to test and experimentation before demonstrated in a real environment. The crane can also operate as a massive rate table, moving the container as it moves on a ship during transit.

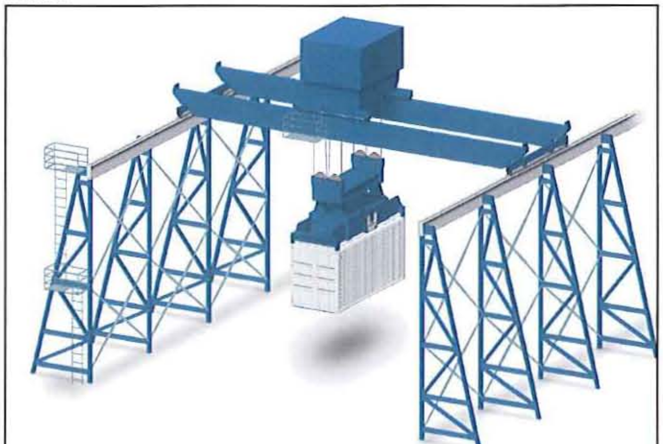


Figure 1. Crane and Spreader Bar Assemblies

B. *Air Collection and Sensor Assemblies*

The DHS CSTB is intended to explore non-invasive mechanisms to surveil shipping containers for contraband, chemical and biological agents. Utilizing the container head space air as a carrier gas allows for presentation of diffused agents to chemical analysis and biological particle detectors. Standard shipping containers have vents which provide a mechanism for extraction of the head space air. Readily available commercial of the shelf (COTS) sensors exist that can be employed in the detection process, however understanding sensor performance requires evaluation in real environments. Complicating these monitoring activities is the desire not to impede the speed of commerce, and thus an air sampling system is being designed and implemented into the CSTB to enable testing of a variety of sampling times and collection/detection methods. In order to minimize impact on the flow of commerce, one approach (SAFECON), is to take advantage of the time that shipping containers are attached to the cranes which are used to load and unload ships by

installing the air sampling system on the crane spreader bar, as illustrated in Figure 2.

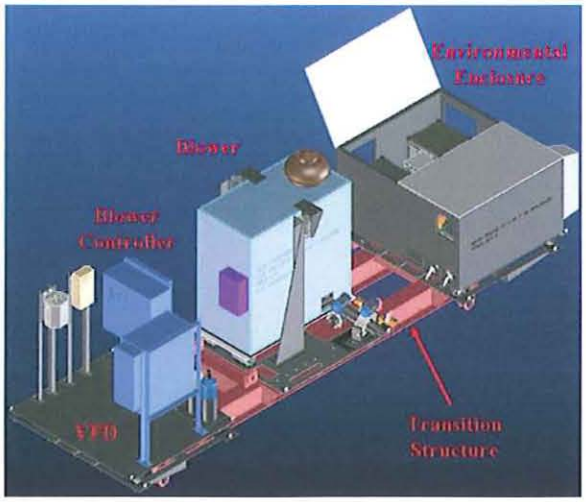


Figure 2. Test bed container air sampling system on crane head block with high volume pump (center) flanked on left by the electrical service and controller, and the environmental enclosure on the right.

Numerous challenges are inherent in implementing a system to perform air collection and detection within this time frame and under real operational constraints. Air sample extraction requires reliably connecting to the container vents with minimal dilution, transporting the sample to the COTS sensors (mostly lab grade), and protecting the equipment from the environment. The system will experience exposure to the harsh environs of a maritime port including the rough handling that cargo containers undergo while being manipulated to and from ships. Consequently the COTS grade sensors are housed in an environmental enclosure which is installed on shock and vibration isolators. The environmental enclosure has sufficient volume to allow for multiple sensors as well as a truth collection station (Summa canisters) which are shown in the block diagram of Figure 3.

The test bed air sampling system is comprised of chemical and particle sensors coupled with an air delivery subsystem that presents a sub volume of air from the shipping containers with major subsystems defined as:

1. Extraction plenum and positioning arm
2. High volume vacuum pump
3. Low volume vacuum pump and manifold
4. Chem/Bio Sensors
5. System control and data recording

Air from the shipping container will be evacuated by a high volume vacuum pump with a low volume vacuum pump performing sub-sampling of the evacuated air. Commercial sensors will be utilized to perform particle detection and chemical analysis. The low volume vacuum pump output is connected to a manifold which provides air at the appropriate pressure and flow rate to the multiple sensors. A common graphical user interface will be used to control and interface with the individual sensors as well as control the experimental apparatus.

The extraction plenum is engaged with semi-standard vents found on most shipping container, by means of a 3-axis robotic arm. A compliant conformal synthetic rubber seal is used to accommodate the irregular surfaces presented by the corrugated container walls. The extraction plenum is manipulated over the vent location in the X-Y dimensions first (parallel to the container wall), and then driven in the Z-dimension (perpendicular to the container wall) to cover the vent. Electromagnets are utilized to apply a compressive force on the seal and ensure a secure mechanical connection is maintained.

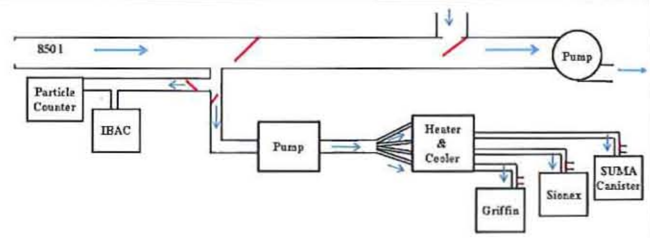


Figure 3. Testbed System Block Diagram

Container air evacuation is provided by a positive displacement high volume vacuum pump via a four inch duct. This pump has an integrated control system that allows for regulation in multiple domains. Standard container vents have a relatively small aperture that air can pass through which results in a choked flow condition, ie increasing the pressure differential will not increase flow through the vent structure. Due to this limitation the pump system is operated in a regulated flow regime of approximately 850 liters per minute (30 CFM). Make up air in the container is provided by the vent which is diagonally located at the far corner. Drawing air in this fashion through the container allows for sampling of the cargos head space air which will contain volatiles and suspended particulates into the four inch duct. A branch line is provided to draw air from the trunk line so the sensors can access the container air. Two modes of operation are required to present this air to the chemical sensors and the particle detectors. Chemical sensors are fed while the main high volume pump is running. The airstream is sub-sampled by small vacuum pump capable of overcoming the approximately -7 PSIG pressure difference. The particle sensors require that the main air stream be stopped and equilibrated to ambient pressure. The sensor timeline therefore is interleaved to make best use of the time available by having the chemical sensors acquire first, followed by the particle sensors acquiring while the chemical sensors perform analysis on the accumulated material in the sorbent.

An over arching control system is wrapped around the various sensors and subsystems. This Graphical User Interface (GUI)

based system allows for human scale real time control of the test apparatus, data acquisition, and data logging. This system is used to inform operators of experiment progress and status as well as inform operators of alert conditions. Configuration of test equipment and methods is done a priori so that experiments are performed by predefined scripts with all relevant conditions being logged to a data base maintained by the main control system.

IV. INITIAL TEST PLAN

A. *Initial Test Goals*

An initial set of testing will be conducted to benchmark the performance of the air collection and detection system and to demonstrate operational feasibility of chemical, biological, and explosives threat simulant detection from shipping container air while on a gantry crane. The system was designed to provide tunability of air flows while minimizing external contamination or dilution of the sample air. In order to test the success of this design, COTS sensors will be used to provide the proof of concept that sample air can effectively be presented to detection equipment. Simulant releases will be monitored using truth sample collection in the container and at the sensors, and the sample environment will be monitored to provide correlative information on performance. An important product of the testing is a definition of the trade-space between sample collection and preparation time and sensor performance. Air collection and sensor operational methods have been designed to achieve detection within 90 seconds (one crane cycle) but will be varied to examine affects of time of detection performance. COTS sensor performance will be evaluated over a limited "realistic" concentration range of chemical and biological simulants sampled from shipping container vents with uncontrolled environmental conditions. Simulants are selected to represent threats, contraband, and common backgrounds. The initial releases will be completed in a cargo container free of packaging; however the ability to alter the container environment is possible and will be completed in follow-on tests. A more detailed description of the COTS sensors, environmental monitoring equipment, and release simulations follows.

B. *Biological Simulant Releases*

A biological analytical sensor standard (BSAS) will be the test surrogate material used to benchmark the air sampling system and biological detection capability. The BSAS is a benign bio-safety level 1 test material that has similar properties to a biological threat (size, fluorescence, etc). The BSAS will be released into the test-bed shipping container by using a dry-air eductor like that shown in Figure 4. The effect of container air movement on simulant dispersion will be evaluated. Test methods to evaluate this as well as collected air-volumes, flow rates, particle concentrations, backgrounds, environmental effects, and system purging effectiveness will be employed to capture component effects on system performance.

Figure 4. Dry Air Eductor

C. *Biological Sensor*

The Instantaneous Biological Analyzer and Collector (IBAC), produced by ICx-S3I Inc., is the biological trigger sensor that is being integrated with the air sampling system. The IBAC sensor, pictured in Figure 5, has been chosen as the main biological trigger sensor due to its maturity, commercial availability, and field operation history. Aerosolized particulates are measured optically and the sensor has a flow rate of 3 liters-per-minute. An onboard proprietary algorithm processes information in real-time and generates a sensor detect when algorithm alarm criteria is satisfied. The sensor is also capable of streaming data to a remote database for viewing and data archiving. Confirmatory identification of biological threats is not being included in the initial tests, however sample collections for down-stream analysis (e.g. PCR) could readily be implemented for future data collection.

Figure 5. IBAC Biological Sensor

D. *Chemical Simulant Releases*

The test bed will utilize diffusion cells for chemical vapor releases. To minimize variables, thermal equilibration blocks will be used to keep the diffusion cells at a constant temperature. The versatility of diffusion cells for vapor releases allows for a range of concentrations for sensor testing. Coupled with the thermal equilibration block, these releases can occur in a controlled way in a field environment.

For the initial test bed demonstration, nine chemicals have been selected to cover a wide range of container screening targets, from toxic industrial chemicals to explosive taggants (Table 1).

Table 1: Chemical Simulant Set for Test Bed Demonstration

Chemical	Representation
Toluene	Toxic Industrial Chemical
m-Xylene	Toxic Industrial Chemical
Cyclohexanone	Drug Marker, Background
Methyl benzoate	Drug Marker
Limonene	Smuggled Agriculture
α-Pinene	Common Background
Dimethylmethyl phosphonate	Nerve Agent
2-Nitrotoluene	Explosive Taggant
2,3-dimethyl-2,3-dinitrobutane	Explosive Taggant

MIT Lincoln Laboratory has evaluated three different sets of diffusion cells that release vapor from the low parts-per-billion range to the middle parts-per-million range. In two of the sets, chemical is added to a bottle, and the rate of loss is directly proportional to the area of an added orifice in the bottle neck (Figure 6). These sets have been designed to release vapor from the low PPB range, simulating a slow leak, to the high PPB range, simulating a macroscopic leak, with orifice diameters ranging from 0.025 inches to 0.550 inches.

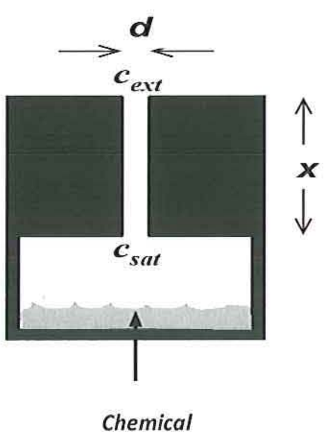


Figure 6. A model of diffusion through an orifice with diameter, *d*.

The versatility of diffusion cells allows for a controlled release over a range of concentrations with the major limitation being the vapor pressure of the chemical of interest. To overcome this limitation and to simulate a high concentration vapor mixture in the low-mid PPM range, jars with 2" diameters are used for direct chemical effusion into the shipping container.

Thermal equilibration blocks mounted in the shipping containers at the test bed are designed to keep the diffusion cells at a constant temperature (Figure 7).

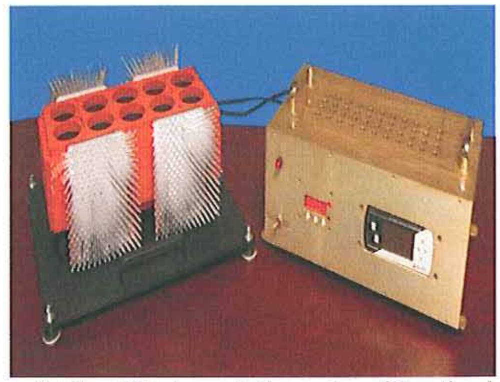


Figure 7. The diffusion cell thermal equilibration block (left) connects to an electrical supply (right) which displays and logs temperature data.

Diffusion cells are pressure fitted into the openings of the block. The heat sinks that jut out of each side of the block radiate away extra heat, while the electrical source supplies current to increase the temperature of the block under cold conditions. These blocks will help guard against extreme variability in equilibration concentration, as temperature of the cells greatly affects the rate of diffusion. At the test bed, the thermal equilibration blocks will allow for controlled chemical vapor releases in changing environmental conditions.

E. Chemical Sensors

Two chemical sensors, the Sionex MicroAnalyzer and the Griffin 450 GC/MS (IcX), were selected for the initial test bed demonstration. The predominant selection criterion was time-to-detect with footprint, required consumables, and cost being secondary. The sensors represent two different technological solutions to the problem of container screening, both offering versatility in method development. Each sensor has its own strengths and limitations.

The Sionex MicroAnalyzer is a GC/DMS sensor. Traditional Ion Mobility Spectrometry (IMS) ionizes a vapor sample and separates the ions by the time it takes them to travel linearly through a drift tube with a homogenous low electric field. Differential Mobility Spectrometry (DMS) takes advantage of the relationship between ion mobility and electric field strength. The vapor sample is ionized and travels through a drift tube with a high electric field applied by a uniform oscillating asymmetric radio frequency (RF), and each ion species travels through the tube with discrete, nonlinear mobility characteristics. A second voltage, the Compensation Voltage, is superimposed on the RF field. Compensation Voltage can be tuned for the stability of a specific ion species,

acting as a filter, or set to scan over a range of voltages for analysis of all ions in a mixture. In scanning mode, ions from a sample are separated by the compensation voltage that allows them to travel through the ion gap and be detected by parallel positive and negative electrometers. Because the field strength is rapidly changing and the ions are being continuously sampled, DMS is a very sensitive detection technology.

In scanning mode, the MicroAnalyzer first separates the sample on a gas chromatography column. The sample is then rapidly separated by compensation voltage. The sensor output is a two dimensional plot of intensity in volts (displayed with a color scale) vs retention time (y-axis) and compensation voltage (x-axis) in positive and negative ion mode (Figure 8).

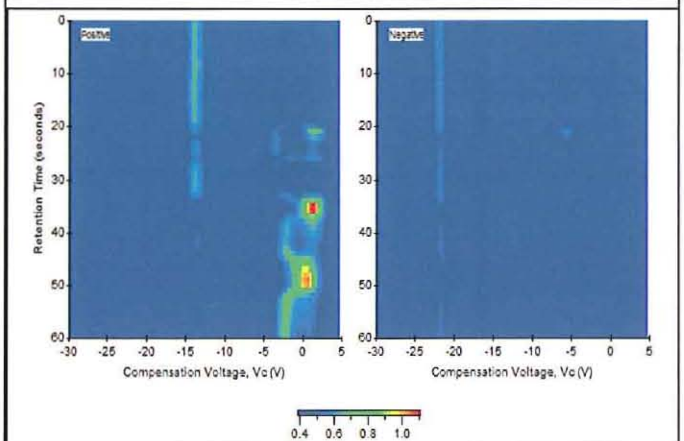


Figure 8. A vapor sample of 0.1 PPM Methyl benzoate and 2-Nitrotoluene is separated first by time through a column (y-axis), then by compensation voltage (x-axis). Neither chemical showed significant negative ion mode activity (right panel).

Each chemical has a signature on the 2-D plot of one or more "spots" of intensity. The sensor does not have a library of signatures for detection of unknowns. Instead, the user builds a library of chemicals of interest and creates analysis tools specific for the chemical set. An algorithm for identification of the chemicals of interest has been developed using average intensity in a defined window on the 2-D plot.

The Sionex MicroAnalyzer is a small, economical, ruggedized sensor that requires very little maintenance. The simplicity of the sensor interface allows the user complete control for method development. However, the sensor cannot be used for the detection of unknowns and high background environments are problematic for positive target detection.

The Griffin 450 GC/MS sensor has a larger footprint than the MicroAnalyzer and requires more maintenance. What these factors affect the ease of fieldability, the Griffin 450 brings the gold standard for laboratory chemical identification, mass spectrometry, into the field. Like the Sionex MicroAnalyzer, the Griffin 450 GC/MS first separates a vapor sample on a gas chromatography column. As sample comes off the column, it is ionized under vacuum, and a spectra is obtained as shown in Figure 9. The sample spectra displays the ion fragments and is compared to known spectra in the NIST library like that shown for 2-nitrotoluene in Figure 10. The top match for each peak is the output of the sensor in real-time. The user can also set up target chemicals and alarm criteria to continuously monitor for a specific set of threats.

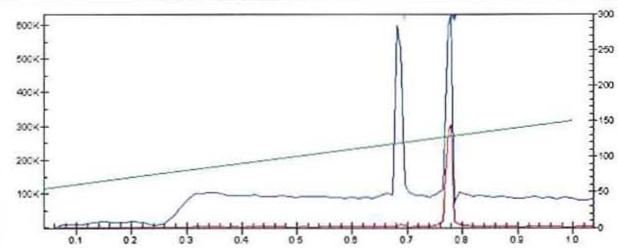


Figure 9. Example Griffin 450 GC/MS Output: Chromatogram of a 0.1 PPM mixture of Methyl benzoate and 2-Nitrotoluene

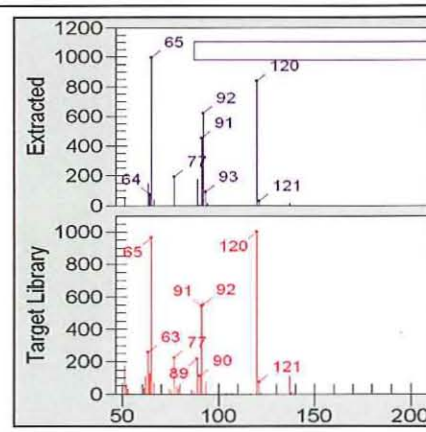
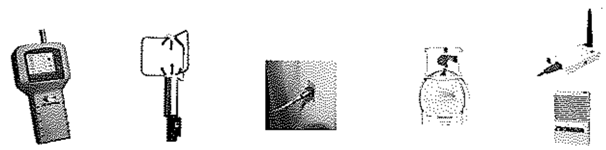


Figure 10. Mass spectra of the peak at 0.78 minutes with the comparison to 2-Nitrotoluene from the NIST library. The y-axis is abundance, and the x-axis is ion fragment size (m/z).

F. Environemental Monitoring and Release Truthing

An independent measure of the biological and chemical releases, background particulate and chemical signature levels, and test operating conditions will be accomplished by using reference sensors. The reference sensors will be positioned within the test-bed shipping containers and the air sampling system. Recorded sensor outputs and summa canister air-collections will assist with benchmarking the sampling system's detection performance and documenting environmental conditions that might influence sample collection and detection. The reference sensors that will be used as shown in Figure 11 and include: 1) MetOne HHPC-6 optical particle counters, 2) Young 81000 sonic anemometers, 3) PCB Piezotronics tri-axial accelerometers, 4) summa canisters, and 5) Omega temperature & relative humidity

sensors. Most signal outputs from each reference sensor will be time-synced and archived at a co-located data acquisition system located inside of each test-bed shipping container. Data archived at each shipping container data acquisition system will also be offloaded to a centralized database system. The optical particle counters provide an independent test-particulate count and mixing reference-benchmark for each simulant release conducted. Co-located sonic anemometers will concurrently provide a 3-axis (i.e. x, y, and z) continuous measure of the air velocity within the shipping container at high data collection rates. This information will aid in determining the level of air mixing/turbulence that occurs within each shipping container. The summa canisters allow for the chemical concentrations to be collected and then later analyzed by gas-chromatography mass-spectrometry at an analytical lab using standard EPA methods. Temperature and relative humidity sensors and the tri-axial accelerometers also positioned within the test shipping container will record test environment conditions and forces incident upon the test-bed shipping containers during testing.



(a) (b) (c) (d) (e)

Figure 11. Reference Instrumentation (a) HHPC-6 Optical Particle Counter, (b) sonic anemometer, (c) tri-axial accelerometer, (d) summa canister, and (e) temperature and relative humidity sensor

V. FUTURE USES OF CONTAINER SCREENING TEST BED

When fully operational, the CTSB will be capable of loading and unloading both 20 and 40 foot standard shipping container just as a typical port crane. Using a custom designed headblock interface the CSTB crane is designed to operate with all makes and models of spreader bars commonly used in US and foreign ports. Test articles include containers with calibrated release mechanisms and full instrumentation for trace sampling throughout the container volume. The CSTB crane supports spreader bar mounted equipment with both tethered and wireless data collection and acquisition equipment. Together, these features enable establishment of a baseline measurement capability for testing third party equipment performance. It also enables experimentation under different background conditions testing new systems under a wide variety of "normal" conditions.

ACKNOWLEDGMENT

REFERENCES